ANALYSIS OF TWO MECHANICAL WIND PUMPING SYSTEMS

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ABSTRACT

A study of two mechanical wind pumping systems was carried out to determine windmill performance at different water depths, working valve cup material, and piston pump barrel material. A 2.44 m (8 ft) rotor diameter windmill with 18 sails, and a 2.44 m (8 ft) rotor diameter windmill with 15 sails, were used. They both had a gear ratio of 3.3:1 which produced a constant stroke length of 19 cm (7.5 in). The furling control springs were adjusted to provide a maximum of 32 strokes per minute on both systems at 10 m/s (22.4 mph) wind speed.

Results from this study showed that there was more friction produced by urethane cups in the pvc piston pump (with urethane lining) than by urethane cups in the all brass piston pump. The pvc piston pump system thus, required a higher wind speed to initiate pumping at a cut-in wind speed of 3.0 m/s (6.7 mph) compared to 2.5 m/s (5.6 mph) for the brass piston pump. The friction caused excessive wear on the working valve cups, a small percentage decrease in volume of water pumped (due to 0.5 m/s lag in cut-in wind speed), and an increase in maintenance cost in the pvc piston pump system.

Based on the pumping curve of each mechanical wind pumping system and a ten year wind speed frequency distribution at 10 m (32.8 ft) height in Bushland, Texas, it was found that the pvc pump was capable of producing an average of 7,953 L/day (2,101 gal/day) of water and the brass pump an average of 8,600 L/day (2,272 gal/day) of water. This 8,000 L/day of water is sufficient to provide water for a household of 5 persons or water for 100 to 125 head of livestock.

INTRODUCTION

Operation and maintenance (O & M) cost is a major concern for many mechanical windmill owners and prospective buyers. It is therefore, necessary to find cheaper and corrosion resistant materials for use in windmills. For this reason the use of polymers as a substitute for conventional metal parts in the design of mechanical wind pumping systems is being tested. The cost of drop pipe and conventional pumping materials at around 50 m [164 ft] depth, is as expensive as the tower and windmill itself.

At the USDA, Conservation and Production Research Laboratory, Bushland, Texas, two mechanical windmills were erected at 10 m heights and used to determine pumping performance under standard test conditions. One windmill was setup using conventional materials such as galvanized drop pipes, metal sucker rods, brass packing head, brass pump, and urethane cups on the working valve. Another windmill was setup with newly designed materials made by a local manufacturing company using pvc pipes (400 psi), fiberglass sucker rods, urethane/epoxy lined packing box, urethane/epoxy lined pvc pump, and urethane cast working valve. The newly designed materials cost less than conventional materials and are highly resistant to corrosion. However, the cost of fiberglass sucker rod is much higher than metal rods but this material is now commonly used because of its strength, flexibility, and resistance to corrosion.

One of the major drawbacks of the conventional materials is corrosion. The rate of corrosion varies from place to place depending on the iron content in the water but its effect is inevitable. The use of PVC pipes eliminates this problem. The PVC pipe is also flexible and light, making it easier to install even through standard towers. However, care should be taken not to over-tighten the joints when fitting, otherwise they will crack. Urethane cups are now a standard material used in place of leather cups due to material characteristics which will be discussed later in the paper. The conventional packing box is made of brass with a rubber O-ring as a seal. The newly designed packing head has urethane/epoxy lining with inverted urethane cups to act as a seal. The newly designed pvc pump barrel has urethane/lining which is lighter and cheaper than the brass barrel.

URETHANE DESIGN CONSIDERATIONS

The choice of urethane in the new design is increasing not only in the windmill industry but also in all other industries. This is because urethane has unique properties such as resistance to abrasion which reduces the replacement of components. The high load bearing capacity helps resist deformation under high pressure. Bondability, which means urethane can bond readily to metal or any other material, often improves metal by making it stronger. Urethane has a wide hardness range where hardness can range from "10 Shore A" (similar to a gum eraser) to "75 Shore D" (similar to nylon). Resilience, which is ratio of energy given up on recovery from deformation to energy required to produce deformation, can be controlled; making it an excellent material for absorbing shock/vibrations. The coefficient of friction remains almost constant over the lifetime of the urethane product.

The coefficient of friction between urethane cups and the urethane/epoxy pump barrel and the coefficient of friction between urethane cups and brass pump barrel was the most important consideration in evaluating the results of this experiment. The factors which influence the coefficient of friction of urethane are important to consider. These were the working temperature, the smoothness of the contact surfaces, the area of contact, and the surface lubrication.

Hard urethane (75 Shore D) has a lower coefficient of friction than the softer urethanes (10 Shore A). Gallagher (1993) suggested that on smooth plastic surfaces, the coefficient of friction of urethane is higher than on rough ground steel probably due to poor thermal conductivity of the plastic.

FIELD TESTS

Standard test procedures as used by Kammand and Clark (1987) were followed to collect data from the mechanical windmills. The furling tension of the windmills was set to allow a maximum of 32 strokes per minute, which optimized the wear of the cups in the pump barrel and the flow rate. Two 48 mm [1.875 in] diameter by 610 mm [24 in] long pvc and brass pump barrels were attached to 6 m [20 ft] pvc and metal pipes respectively. Pumping depth was simulated by adjusting the discharge pressure using a back-pressure valve and pressure tank.

The water flow rate, water pressure, wind speed, and stroke speed of the pump rod were recorded at 1-minute averages using a microdatalogger. Instrumentation of the windmill was set up as shown in Fig 1. Flow rate was measured using a flowmeter and a back-pressure valve and a pressure tank were used to regulate the pumping pressure which was measured with a pressure gauge. A pressure transducer was used to record the pressure into a microdatalogger. Data were collected for depths of 30 m [98 ft], 45 m [148 ft], and 55 m

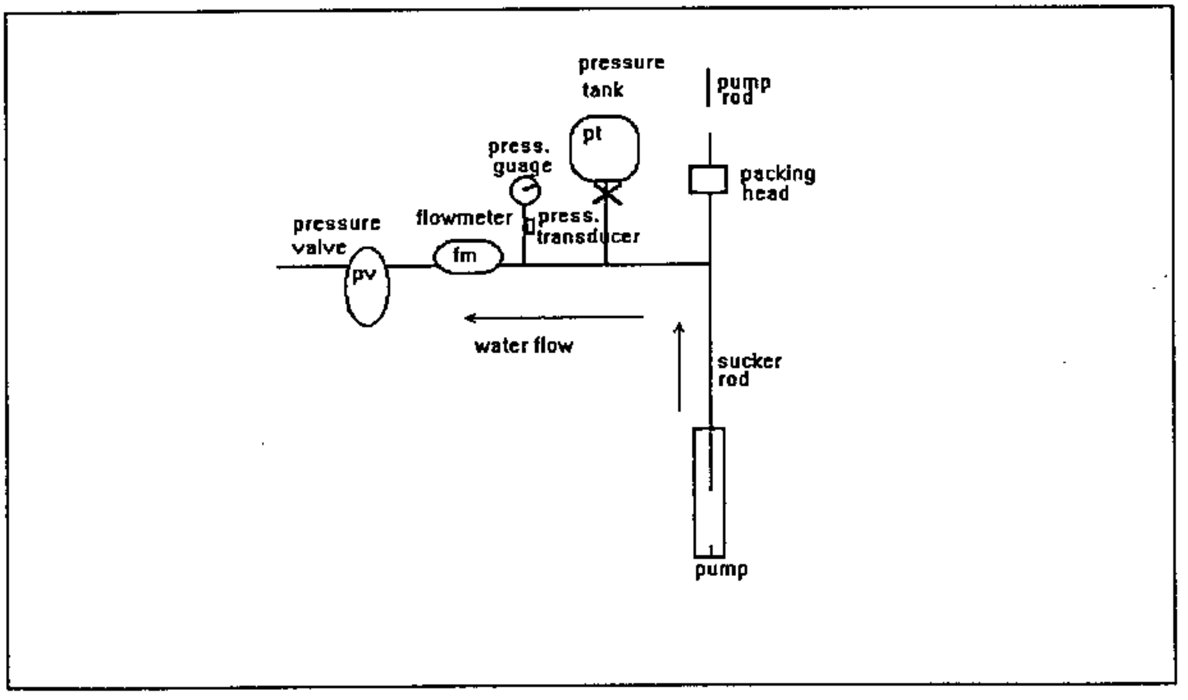

Figure 1 Schematic of instrumentation used to measure performance of mechanical windmills.

[180 ft]. Another set of data was collected at 45 m depth with the pumps switched between the two windmills. The raw data were processed daily using SAS software and graphs were plotted to observe performance and detect any data errors or instrumentation failures. A summary of the data was made after at least 1000 data points were collected at each wind speed bin (0.5 m/s). Pumping conditions on both windmills were kept the same and any glitches which occurred were eliminated from the data summary.

EFFICIENCY OF THE PUMPING SYSTEMS

In a mechanical water pumping system two major power losses are encountered. These occur when wind power is converted to pump power and when pump power is converted to hydraulic power. The overall system efficiency is the ratio of the hydraulic power to the wind power. Other losses are due to frictional forces between water and pipe and between cups and pump barrels.

System efficiency of the windmill is the ratio of the hydraulic power to the wind power and is given as

$$\eta_{syst} = P_{hydraulic}/P_{wind} \tag{1}$$

where η_{syst} is the overall system efficiency,
$P_{hydraulic}$ is the power required to lift the water, and
P_{wind} is the available power from the wind.

Pump power is determined from the torque produced by the pump due to weight of water lifted, weight of pump and sucker rods, friction between the valve cups and pump barrel, and friction of water against the pipes.

$$\text{Pump power(Pp)} = \text{Rotor torque(Tr)} * 2*\pi*N/60 \tag{2}$$

where N is the strokes per minute.

To determine rotor torque, the sum of all forces acting on the rotor such as sucker rod weight, pump rod weight and weight of water during uplift are considered and this is multiplied by half the stroke length (Fraenkel, 1986).

$$\text{Total force (Ft)} = \text{Rod weights} + \text{water weight} + \text{friction} \tag{3}$$

and

$$\text{Rotor Torque(Tr)} = \text{Ft} * S/2 \tag{4}$$

where S is the stroke length.

The water weight is directly related to the total head of the water lifted from the pump. It is the sum of the delivery head and static head. The field test pressure from the pressure gauge is added to the static head to give total head.

$$H_{total} = H_{delivery} + H_{static} \tag{5}$$

Then from Equation 2, the pump power is given as

$$P_{pump} = Ft * S/2 * 2*\pi*N/60 \quad (6)$$

The efficiency of the pump can be determined by the ratio of the pump power to the hydraulic power which is the product of the flow rate and the total head.

$$\eta_p = 16.321 * Q * H_{total} / P_{pump} \quad (7)$$

where η_p is the pump efficiency and
Q is the flow rate (liters per minute).

The power that can be extracted from the wind determined by the area of the rotor, and the speed of the wind. The follow equation is used to calculate the power available from the wind:

$$P_{wind} = 1/2\, \rho\, A\, V^3 \quad (8)$$

where ρ is the air density,
A is the rotor area, and
V is the wind speed.

The above mentioned equations were used to determine the pump efficiencies of both the brass pump with urethane cups and the pvc pump with urethane cups. The overall system efficiencies were also determined for each pumping system.

RESULTS

Both the pvc and brass pumps were tested on each windmill; therefore, the slight variation in windmill rotors was removed from the test. Data will be reported for the 45 m pumping depth and for only one of the windmills. Data for both windmills and the two other two pumping depths showed similar results. Figure 2 shows that the brass pump starts pumping water at a wind speed of 2.5 m/s (5.6 mph), which is 0.5 m/s [1.1 mph] before the PVC pump. This is due to the higher coefficient of friction between urethane to urethane than urethane to brass. The difference in starting wind speed was evident at all pumping depths and with both windmills. The difference in stroke speed at wind speeds above 10 m/s (22 mph) was attributed to differences in furling although the furling spring was adjusted the same.

The average pump efficiency for the 45 m pumping depth averaged about 83% using the 48 mm [1.875 in] diameter piston pumps. There was no significant difference in the efficiencies of the pumps once they started moving (Figure 3). It was the initial movement that required additional torque. The losses in pump efficiency were due to mechanical losses from the gears and frictional losses in pipes and cups.

The maximum overall system efficiency was reached at a wind speed of 4 m/s with a value of 16% for the brass pump and at a wind speed of 4.5 m/s with a value of 13% for the urethane-line pvc pump (Figure 4). The delay in overall efficiencies for the pvc pump clearly shows the delay in initiating water flow caused by the high friction in the pump. Again, after movement is started, the efficiencies are similar.

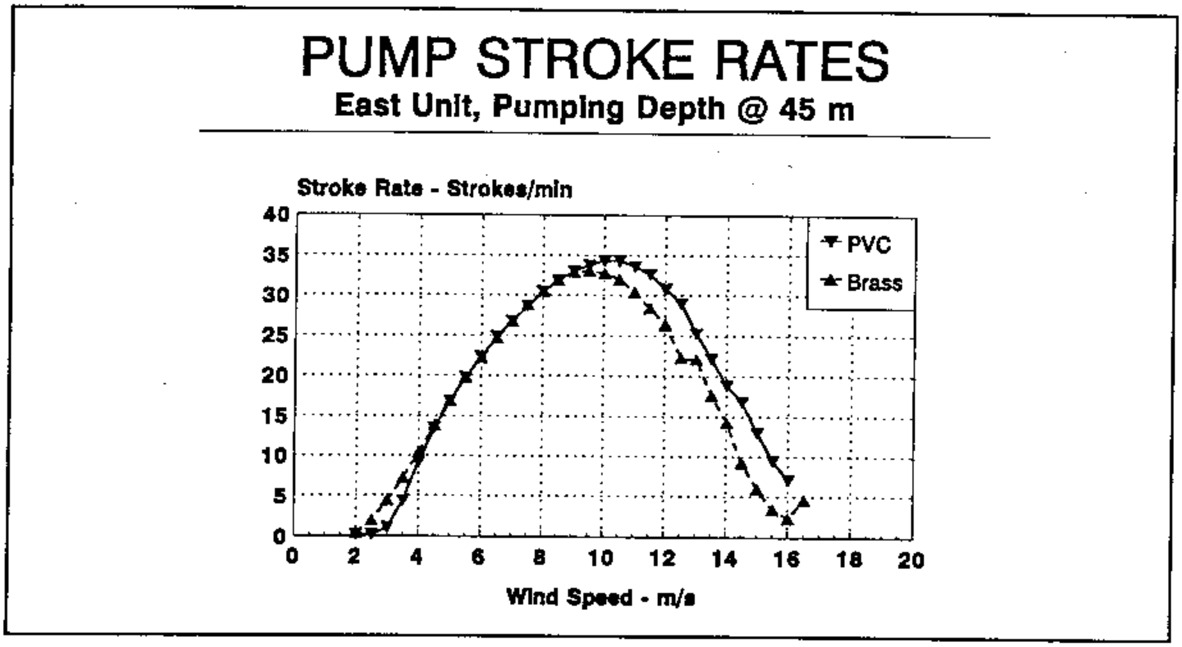

Figure 2 The stroke speeds for the all brass pump and the urethane-lined pvc pump for various wind speeds when the pumping depth was 45 m.

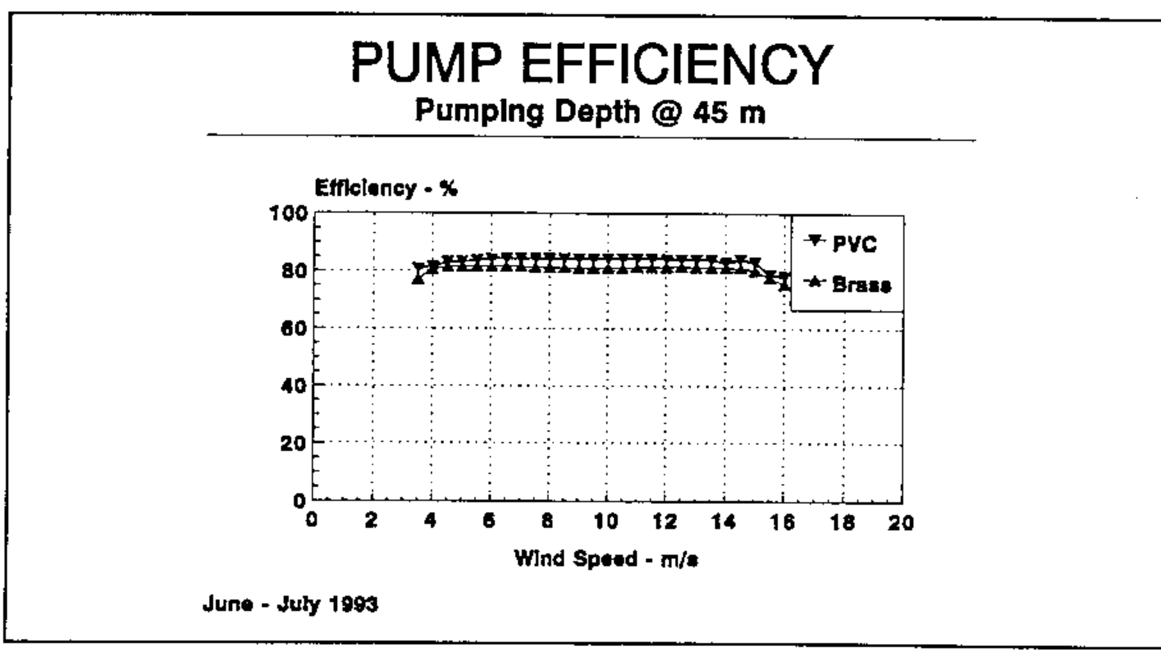

Figure 3 The mechanical efficiency was almost the same for the two pump materials once the pumps started lifting water.

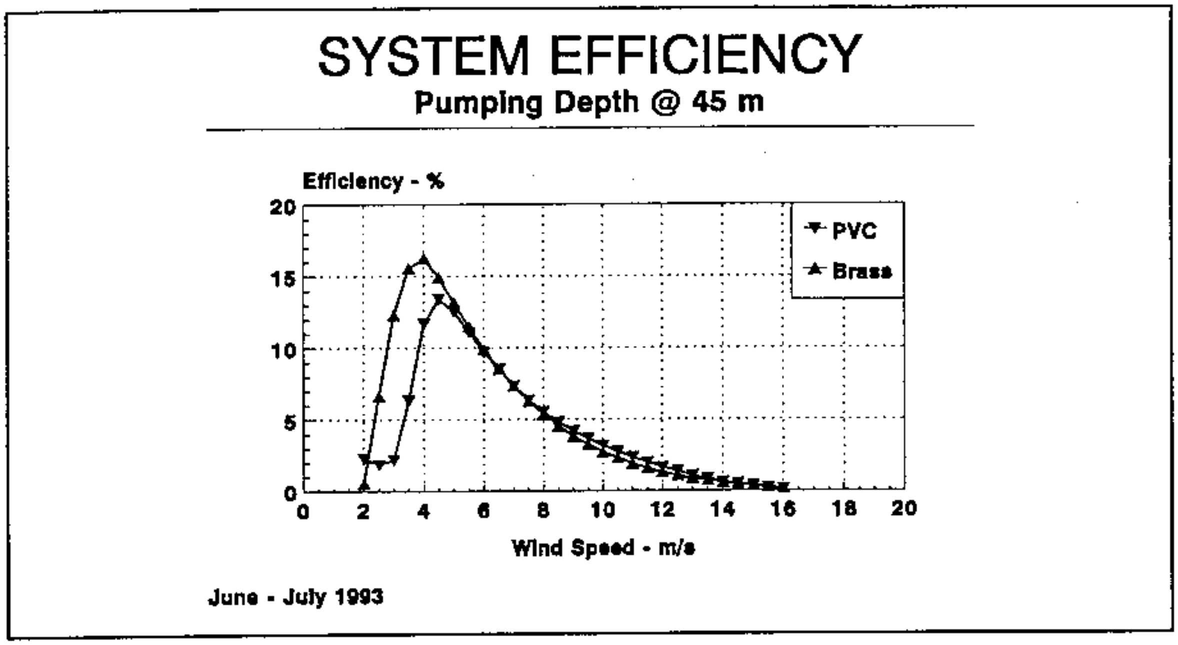

Figure 4 Overall system efficiencies for the two pumps examined indicating that the brass pump had less friction between the cups and pump barrel.

Probably the best overall performance indicator is the daily flow capacity of a windmill pumping system. Each flow curve was used along with a 10-year monthly wind speed histogram to calculate the average daily water pumped for each month. The wind speed histogram was developed from hourly wind speed data collected at a height of 10 m at Bushland, TX from 1983 to 1993. Figure 5 shows the average daily water pumped for each pump. The brass pump with urethane cups averaged 8600 L/day (2272 gal/day) and the urethane-lined pvc pump averaged 7953 L/day (2101 gal/day) of water. The difference does not appear to be significant, except that the extra water would provide for 10 additional beef cows or 1 additional family in a developing country.

CONCLUSIONS

Choice of pump material had no effect on the mechanical efficiency of the windmill once the windmill overcame the initial starting torque. However, the pump material did have an effect on the start-up wind speed. The urethane-lined pvc pump had a higher friction force at low wind speeds; thus reducing the total volume of water pumped. Hence using a brass pump barrel instead of a urethane-lined pvc pump barrel provided 647 L/day (171 gal/day) more water. This amount of water would provide for 10 additional beef cows or 1 additional family of four in a developing country. The frictional force is reduced once the pump is started and the pumping rates and efficiencies are about the same. Care should be taken to select good and strong urethane check valves to prevent frequent breakages.

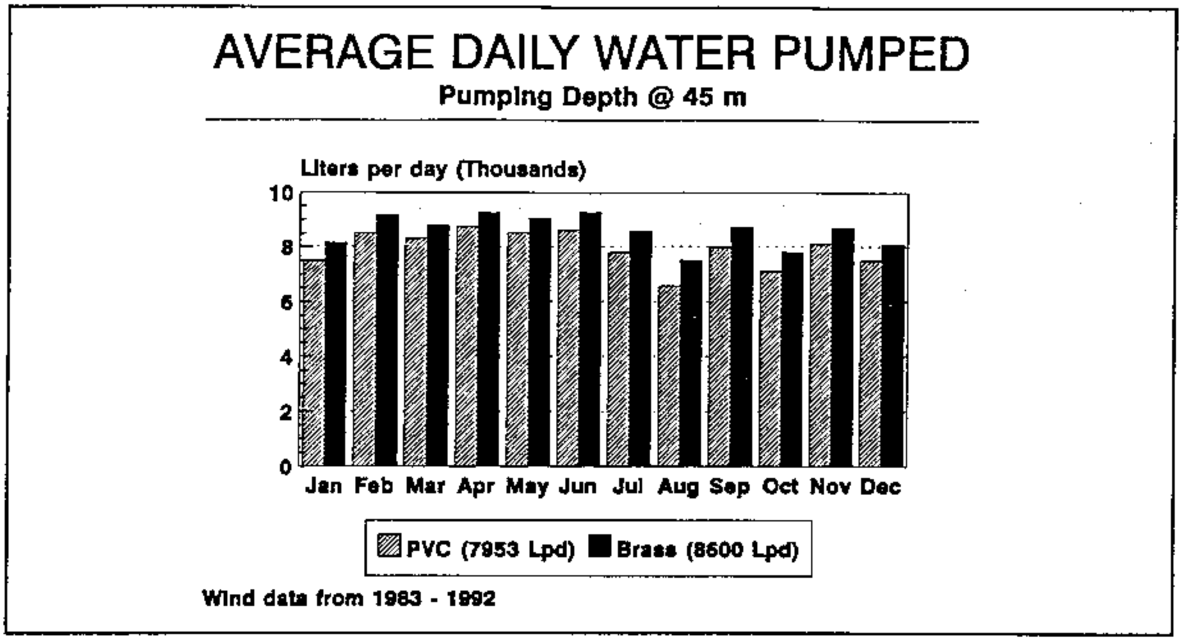

Figure 5 The volume of water pumped per day was predicted using a 10-year monthly wind speed histogram.

REFERENCES

1. Fraenkel, Peter. 1986. Water Pumping Devices; A handbook for users and choosers. Food and Agriculture Organization of the United Nations (FAO), Intermediate Technology Publications, London.

2. Gallagher Corporation. 1993. Urethane Products Engineering Brochure, 3908 Morrison Drive, Gurnee, Illinois 60031.

3. Kammand, F.Z., R.N. Clark, and R.G. Davis. 1987. Performance Evaluation of a Piston Pump for Windmills. Proceedings of Windpower'87, October 5-8, 1987, American Wind Energy Association, p 214.